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ABSTRACT

Tagged Atlantic menhaden, *Brevoortia tyrannus*, along with nontagged controls were held captive in a natural cove at Beaufort, North Carolina from December 1970 to January 1972. Rate of growth, annulus formation and increase in scale diameter was the same for control menhaden and those tagged one, two or three times. Growth of fish in the cove was similar to all other previous estimates obtained from back-calculated length-frequency studies. Both development of scales and growth of fish were correlated with annual temperature changes, and only one annulus formed during the year. Larval menhaden, which were thought to require water of low salinity to metamorphose into normal juveniles, transformed in the cove where the salinity was 30 ‰. An "inner ring," which forms on the scales when menhaden are 50 to 70 mm and occurs on about 15% of the scales from commercial Atlantic menhaden landings some years, may represent a true annulus formed by very small juveniles from Long Island Sound, New York.

The assumption that growth and annulus formation are similar in tagged and nontagged fish in the natural population is often made in mark-recapture studies. Over 1.3 million Atlantic menhaden, *Brevoortia tyrannus*, were tagged with internal ferromagnetic tags and released from 1966 through 1972 to determine migration routes and mortality rates (Kroger and Guthrie 1973; Dryfoos, Cheek, and Kroger 1973). Our study was conducted to find out if tagging had an effect on growth rate and annulus formation. This report describes the growth rate and annulus formation in tagged menhaden held captive for over a year with nontagged controls in a blocked-off natural cove. Growth of juvenile menhaden which entered the cove as larvae is also discussed as is the size range of menhaden from areas of the Atlantic Coast at the time the first annulus formed.

METHODS AND MATERIALS

The experiment was conducted at Beaufort, N.C., from December 1970 to January 1972 in a mud-bottomed cove that had an entrance 45 m wide which allowed normal tidal fluctuations (Fig. 1). The surface area of the cove ranged from 0.60 ha at low tide to 1.53 ha at high tide when the large, flat, marshgrass area surrounding the cove was flooded. Mean depth was 1.6 m and the deepest point was 3.0 m at low tide. Daily tidal fluctuations averaged 0.6 m. Salinity averaged about 30 ‰ and monthly readings ranged from 24 to 36 ‰.

The opening to the cove was blocked with a 2.9-cm stretched mesh net, 69.2 m long by 6.1 m deep, constructed of number 18 twine. A lead core line with 57-g lead weights every 23 cm held the net to the bottom. A polyethylene cork line had 8.9 by 10.2-cm corks every 23 cm and was held above the water surface 15 to 40 cm with 1- by 3-m wooden frames supported with 0.1-m^3 Styrofoam[1] floats (Fig. 2). Prior to the start of the experiment, rotenone and gill nets were used to remove large predatory fish in the cove.

Juvenile menhaden were obtained from a commercial purse seine near Cape Lookout, North Carolina, and transferred to the cove in an aerated 1.42-kiloliter circular Fiberglas tank. Fork length measurements and scale samples from 395 fish were taken and a numbered ferromagnetic tag, 7.0 by 2.5 by 0.4 mm, was injected with a tagging gun into the body cavity of the fish from the base of the left pectoral fin (Kroger and Dryfoos 1972). Six hundred nontagged, control menhaden from the same group and which averaged the same mean length as the tagged fish

[1] Trade names referred to in this publication do not imply endorsement by the National Marine Fisheries Service.

FIGURE 1.—Aerial view of the cove with barrier net in place.

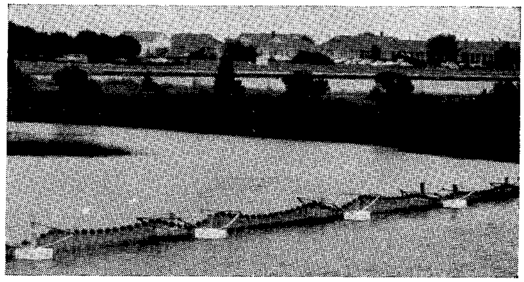

FIGURE 2.—Barrier net held above the water with Styrofoam supported frames.

were released into the cove at the time of tagging.

We sampled tagged and control menhaden about every 6 weeks by seining the cove at low tide with a 1.27-cm stretched-mesh haul seine, 53 m long by 3 m deep. During the first four seinings, we tagged, sampled scales, and released some of the control fish and previously tagged fish back into the cove so that a series of scales and growth data could be obtained. An electronic tag detector was used to distinguish tagged fish from the controls. Scales were mounted between glass slides and examined with an Eberbach scale projecting machine at a magnification of 40×.

RESULTS AND DISCUSSION

Growth

Most of the 395 tagged and 600 control menhaden (average 117 mm) released in the cove on 8 December 1970 escaped or died. Sixteen tagged fish were recovered by commercial menhaden fishermen, indicating that many escaped (probably during extreme high tides). Others were probably eaten by bluefish, *Pomatomus saltatrix*, which grew from 85 mm when sampled on 20 May to over 300 mm when sampled at the end of the experiment. Although many fish were lost, data on growth and scale formation were collected from 92 menhaden of which 49 were tagged once, 35 twice, and 8 three times.

No difference in the rate of growth of single, double, and triple-tagged fish or control fish was detectable (Table 1). Even though all the original controls had been tagged prior to August, growth through July appeared the same as for fish tagged one, two or three times. The mean lengths of single, double and triple-tagged fish and control fish were not significantly different on any sampling date when sample size was sufficient for analysis (t-test, $p > 0.05$). These results strongly suggest that growth of tagged menhaden released in the natural environment is also the same as in nontagged menhaden.

TABLE 1.—*Mean lengths and ranges of control and tagged menhaden sampled from 8 December 1970 to 29 November 1971*

	Controls			Tagged Fish—Number of times tagged: One			Two			Three		
		Length mm			Length mm			Length mm			Length mm	
Date	Number measured	$\bar{x}$	Range	Number measured	$\bar{x}$	Range	Number measured	$\bar{x}$	Range	Number measured	$\bar{x}$	Range
1970												
8 December	395	117	105–143	—	—	—	—	—	—	—	—	—
1971												
12 February	76	118	107–146	12	119	107–144	—	—	—	—	—	—
23 March	41	121	107–137	23	124	113–138	3	122	117–125	—	—	—
20 April	40	126	114–139	32	129	115–153	12	131	116–153	—	—	—
20 May	1	143	—	4	143	128–153	10	141	136–147	2	140	138–141
9 July	3	172	166–181	10	172	167–178	12	170	162–178	2	174	167–180
10 August	—	—	—	1	195	—	5	183	179–188	3	187	186–188
13 October	—	—	—	1	201	—	1	200	—	1	199	—
29 November	—	—	—	1	218	—	—	—	—	—	—	—

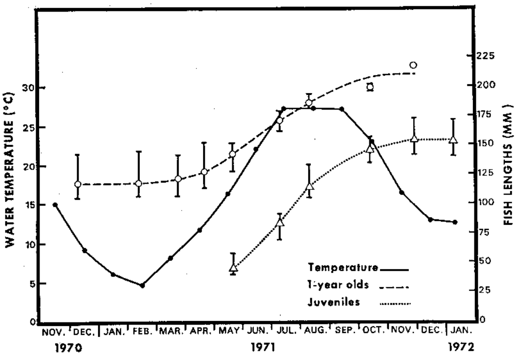

FIGURE 3.—Plot of mean monthly temperature and sizes and range in size of 1-year-old and juvenile menhaden from November 1970 to January 1972. Lines were fitted by sight.

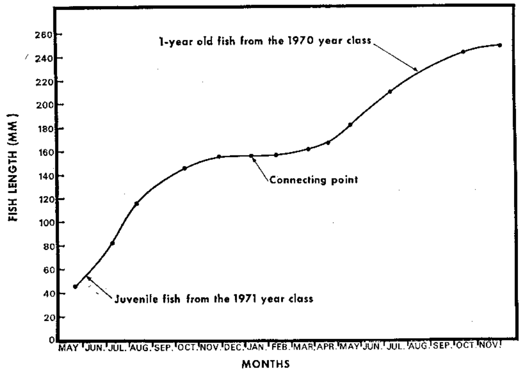

FIGURE 4.—Two-year growth curve constructed when 1-year growth curves for two adjacent year classes were connected.

Differences in rates of growth from December 1970 to November 1971, when the age I menhaden increased from an average of 117 to 218 mm, appeared directly correlated with changes in water temperature (Fig. 3). Growth was slow during the winter until April when the water warmed; growth was rapid throughout spring and summer and then ceased as the water cooled in October and November. The data presented in Figure 3 suggest that rate of growth increases in the spring at the same temperature (about 15 C) that causes a decrease in rate of growth in the fall. Food availability differences between spring and fall could possibly have caused this growth rate change.

In addition to 1-year-old menhaden, useful growth information was obtained from juveniles which entered the cove through the mesh of the barrier net as small larvae in the spring and became trapped when they grew too large (Fig. 3). These juveniles were abundant in the cove and about 25 were collected on each sampling date from 20 May 1971 to 10 January 1972. They evidently were present in the cove on 20 April but were less than 30 mm; menhaden larger than 30 mm are usually retained in haul seines with 1.27-cm stretched mesh. We used the juveniles to determine when growth slowed down in the fall because nearly all the tagged age I menhaden had been removed from the cove by November. A plot of menhaden growth for 2 years (Fig. 4) was constructed by connecting the two growth curves illustrated in Figure 3.

The occurrence of the juveniles in the cove represents the first reported instance where larval Atlantic menhaden in the natural environment have metamorphosed into juveniles in water averaging 30 ‰ salinity. During the period of metamorphosis, January to May 1971, no salinity readings below 26 ‰ were obtained. In a laboratory experiment, larvae metamorphosed in salinities of 15 to 40 ‰ but one-third of the juveniles, as determined from radiographs, developed slightly crooked vertebral columns (Lewis 1966). Wilkens and Lewis (1971) speculated that larval menhaden probably cannot metamorphose properly in fresh or highly saline water, but we have often collected recently metamorphosed juveniles (30 mm) in water with salinities over 15 ‰. Although we did not examine the vertebral columns on radiographs, none of the 238 juveniles collected from the cove had obvious crooked vertebral columns as we have observed in juveniles from other geographical areas (Kroger and Guthrie 1971).

Growth of juvenile and 1-year-old menhaden in the cove approximated growth rates determined in other studies. Juvenile menhaden in White Creek, Delaware grew 0.70 mm per day from June to September (Pacheco and Grant[2]) as compared to the 0.83 mm per day

[2] Pacheco, A. L., and G. C. Grant. Unpublished manuscript. Studies of the early life history of Atlantic menhaden in estuarine nurseries. Part II—Occurrence, abundance, and growth of young menhaden in a tributary creek of Indian River, Delaware, 1957. National Marine Fisheries Service, Atlantic Estuarine Fisheries Center, Beaufort, N.C. 28516.

for juveniles in the cove during the summer. The average length of juvenile and 1-year-old menhaden caught in Chesapeake Bay was back-calculated to be 125 and 200 mm in December (McHugh, Oglesby and Pacheco 1959). C. E. Richards, using menhaden caught in the North Carolina fall fishery, back-calculated the length of juveniles at 130 mm and 1-year-old menhaden at 210 mm in December (Reintjes 1969). Growth of three menhaden (average 130 mm) tagged in Chesapeake Bay on 22 July 1969 and recovered 125 days later in North Carolina showed an increase of 0.46 mm per day. This is the same growth rate calculated for juvenile menhaden in the cove during this summer-fall period in 1971. Thus, former growth data on Atlantic menhaden suggest that the menhaden in the cove grew at approximately the same rate as menhaden caught in the commercial fishery.

ANNULUS FORMATION

No visual difference in growth of scales and development of the first annulus on control menhaden and those that had been tagged one, two or three times could be detected. Tagging did not cause a false annulus to form on any of the scales examined. Increases in scale diameter were undetectable during the winter. The annulus started forming in April when menhaden began growing rapidly in the warmer water, and scales continued to increase in diameter throughout the summer and fall until the end of November when the water cooled. As reported by McHugh, Oglesby and Pacheco (1959) and June and Roithmayr (1960), annuli began forming very near the place that had represented the edge of the scale at the end of the previous growing season.

Our study, in addition to showing that growth and scale development of tagged menhaden are the same as in nontagged fish, served to reinforce our method of determining ages of menhaden. Rush (1952) and Westman and Nigrelli (1955) were the first to report that annuli could be used to determine ages of menhaden, and McHugh, Oglesby and Pacheco (1959) used the method in an extensive study of menhaden caught in Chesapeake Bay. June and Roithmayr (1960) conducted a long-term study to determine the validity of the scale reading method which involved sampling the Atlantic menhaden purse seine landings for 5 years and conducting a laboratory holding experiment with known age menhaden. They showed that the age of Atlantic menhaden could be determined by counting annuli. The most frequent disagreement between scale readers was recognition of the first annulus. Locating the first annulus was also the primary source of error in determining ages of a similar commercial fish, Pacific sardine, *Sardinops sagax* (U.S. Fish Wildl. Serv. 1965). The tagged and control fish in the cove laid down annuli in the spring that were consistently recognized by our scale reading personnel. Since no menhaden scales showed any sign of forming an annulus at any time other than in the spring, we assumed, as did June and Roithmayr (1960), that menhaden form only one annulus per year.

It is difficult, through use of length frequencies, to determine ages of menhaden from along the Atlantic Coast because of the large size range within year classes and between years. Growth information from our experiment and other menhaden studies indicate that menhaden are usually between 50 and 165 mm when they form their first annulus. In September 1970 and 1971 we collected groups of juvenile menhaden in estuaries of Long Island Sound, New York that averaged 38 mm (range 31 to 53), 73 mm (range 60 to 109) and 107 mm (range 60 to 140). We also collected juveniles in six Chesapeake Bay estuaries which averaged 134 mm (range 92 to 171) in 1970 and 105 mm (range 87 to 130) in 1971. Groups of juveniles from North Carolina to Florida averaged 93 mm (range 63 to 153) in September 1970 and 82 mm (range 58 to 121) in 1971. By November, when growth most likely had ceased, juveniles from along the coast probably ranged from 40 to 185 mm which is a greater range than previously determined. Since these lengths represent the approximate size of the fish when the annulus forms, we can assume that smaller 1-year-old menhaden may average 145 mm shorter than larger 1-year-old fish the following year. Juveniles of the succeeding year class are probably only 20 or 30 mm shorter than the small 1-year-old menhaden in May. If the juveniles grow at a faster rate than 1-year-old menhaden as in the cove (Fig. 3), some will probably be bigger than the small 1-year-old fish by fall. The large overlap in lengths between adjacent year classes makes scale reading the most reliable age determining method for menhaden.

The annulus formed by menhaden which are spawned in the summer in Long Island Sound probably represents what menhaden scale reading personnel refer to as an "inner ring." In some years this ring occurs on about 15% of the scales collected from samples of the commercial catch of Atlantic menhaden and, as indicated from back-calculated lengths, forms when fish are about 50 to 70 mm.

In 1970 we examined scales from juvenile menhaden infested with the isopod parasite, *Olencira praegustator,* to determine if the parasite affects growth rate and scale development; but no "inner ring" was visible on these scales. Since juvenile menhaden 30 to 50 mm are found only in Long Island Sound estuaries in late September, we think that when their first annulus forms the following spring, that it represents the "inner ring." More research is needed to substantiate this hypothesis and in 1972 we tagged 5,500 of these summer spawned juveniles to find where they occur in the commercial catches in succeeding years and to determine if their presence is correlated with those with "inner rings."

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